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Radar Tomography of Moving Targets

On behalf of Sensors Directorate, Air Force Research Laboratory

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14. ABSTRACT

This report results from a contract tasking University College London as follows: The contractor will investigate and develop a baseline design and an engineering approach to demonstrate the concept of Tomography of Moving Targets (TMT). TMT is understood as the signal processing and analysis of geometrically diverse, multi-frequency, ultra narrow band and conventional radar data. Simulations and analyses will be used to assess effectiveness of TMT for achieving the stated goals of increased target detection and improved target location.

15. SUBJECT TERMS
EOARD, Signal Processing, Multistatic Radar, Tomography

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1. SUMMARY

The objective of this work is to use CW (continuous wave) radar to perform tomographic imaging of moving targets (TMT), thereby presenting a technique for generating imagery with high spatial resolution from low bandwidth radar transmissions.

The high spatial resolution is obtained by applying the principles of tomography to a multi site narrow band CW radar system that illuminates the target over the complete angular range of 360 degrees. Experiments are described which allow this approach to be compared with more conventional high bandwidth ISAR imaging.

For the purpose of this investigation, data has been obtained from a real stepped frequency ISAR system then adapted to emulate CW results. A number of MATLAB simulations are also being developed to examine this concept.

This technique provides useful insight into the limitations on achievable resolution. These are formulated for the simple case where it is shown that both the range resolution and cross-range resolution are limited to a value of $\lambda/2$ if ambiguities are to be avoided.

This report summarises progress on the TMT project in the last phase of work (June '05- Sept '05). The main activities on the project have been to investigate the theory of the spatial resolution limitations of CW, SAR and ISAR radar and the theory on tomographic processing. The following sections briefly review the activities concerned.

In addition, the future work for the final phase of the project is outlined where the application of tomographic techniques to a multistatic Continuous Wave (CW) radar geometry are investigated to validate this theory.

2. BACKGROUND

This study is investigating the validity of distributed UNB for radar imaging applications. The use of CW is attractive if it offers the potential of greatly improved spectral efficiency by trading resolution achieved by bandwidth for resolution achieved by spatially diverse angular imaging. Hence the main topic of this research is to understand the fundamentals of TMT and establish the range of suitable applications that subsequently arise.

This topic is very much in its infancy and almost no research exists in the literature. Consequently much basic research is required to determine fundamental performance limitations and thence the range of useful applications.

3. PROGRESS

3.1. Nominal resolution limits

In this section we examine the limitations on achievable spatial resolution and speculate on ways in which this might be improved. In standard radar designs, the maximum possible sampling frequency is determined by the Nyquist rate. Thus the limits on resolution essentially result from the fact that the sampling rate can only usefully be set at twice the highest frequency present (i.e. the Nyquist rate) and of course the highest frequency is the illumination frequency. Here we show that this is manifest in both the time (i.e. pulse bandwidth) domain and the cross-range or angle domain.

Consider a hypothetical scenario of a real aperture UNB radar detects a moving target travelling from $+\infty$ to $-\infty$ as shown in figure 1.

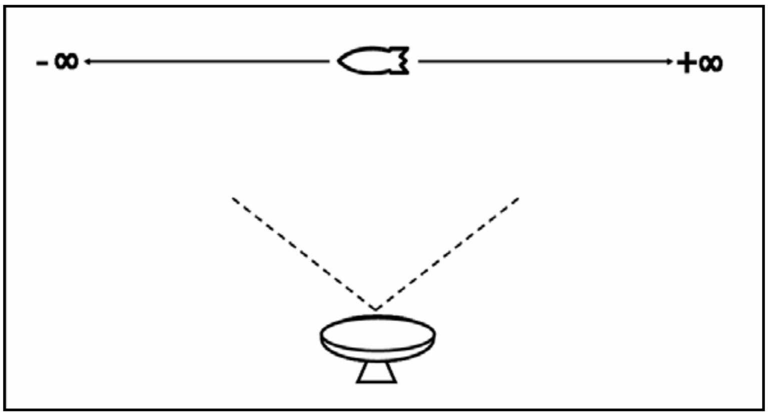

Figure 1: A hypothetical scenario of a real aperture UNB radar detecting a moving target travelling from $+\infty$ to $-\infty$

Range resolution is given by $\delta r = \frac{c}{2B}$, where δr = range resolution, c=speed of light and B=bandwidth.

In the extreme case, the bandwidth is equivalent to the carrier frequency.

Therefore the range resolution is limited to $\delta r = \frac{c}{2f_0} = \frac{\lambda}{2}$, where f_0 = carrier frequency, i.e. the best resolution achievable is half the wavelength of the illuminating radiation.

If cross-range resolution is considered then the Doppler frequency measured by the radar is given by $f_D = \frac{2v_r}{\lambda}$, where f_D = Doppler frequency, v_r = radial velocity. In standard radar design, once again the maximum Doppler frequency is also limited to that of the carrier frequency. This occurs when $v_r = \frac{c}{2}$. If the radial velocity measured equals half the speed of light, then the target has definitely travelled to what is considered ∞. In that case, the radial velocity is equivalent to the tangential velocity v_t. Thus the cross-range resolution is limited to $\delta cr = v_t.\Delta_t = \frac{c.\Delta_t}{2} = \frac{c}{2f_0} = \frac{\lambda}{2}$, where Δ_t = pulse length.

Again it is seen that the cross-range resolution is ultimately limited by the value of the carrier frequency and is also equal to half the wavelength.

Further, we can apply this form of logic to the case of SAR imaging. Here the cross range resolution is given by: $\delta cr = \dfrac{\lambda}{4\sin(\Delta\theta/2)}$ (which is approximately equivalent to ISAR where $\delta cr = \dfrac{\lambda}{2.\Delta\theta}$). If the half wavelength limit is inserted for the best possible resolution then this cross-range limit is obtained at a 60° look angle ($\Delta\theta$).

It is possible that better resolution values may be obtained, however, the frequencies that have to contribute are under sampled and therefore ambiguities develop.

3.2. Experimentation

To examine the concepts introduced in the previous sections both simulations and full scale ISAR turntable data (modified to emulate a multistatic CW system) are used. Only the results from the full scale turntable measurements are presented here.

The configuration of the real ISAR system is that of a chirp stepped-frequency ISAR viewing an object on a turntable which steadily rotates 360 degrees. At each integration time, a number of pulses are transmitted and received by the radar over multiple channels using multiple forms of polarisation. Each pulse consists of a number of stepped frequency waveforms. As the object on the turntable steadily turns, the radar measures the range and Doppler of its scatterers.

The ISAR is a 10 GHZ radar and currently a 500 MHz bandwidth has been selected so the range resolution is 30 cm however is will be extended to 6.667 cm. Currently, the samples from the entire 360 degree angles are subdivided into 171 subapertures of 2.1 degrees in length which means that the cross-range resolution is 40 cm. However, in accordance with the above theory, these subapertures are to be lengthened to 60 degrees each to achieve a cross-range resolution of 1.5 cm. This means that only 6 CW radars are required to produce the image.

The multilook technique was used to compare the range-Doppler results to the final narrowband tomographic technique. The multilook technique is shown in figure 2 where a range-Doppler image of each small subaperture are superimposed to create the full image.

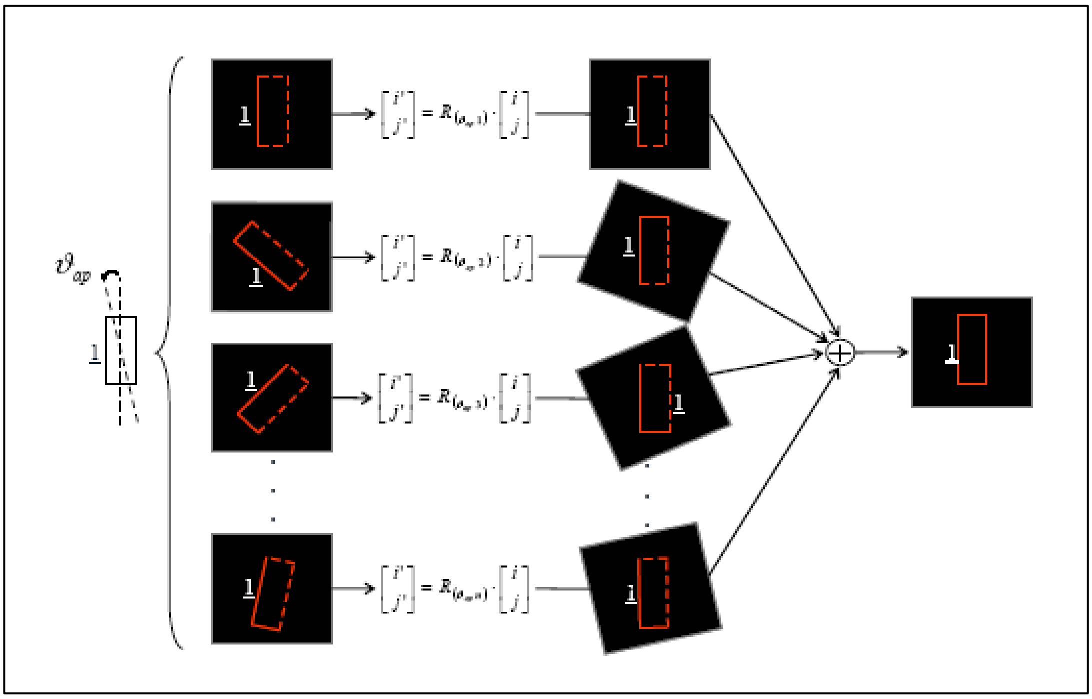

Figure 2: Multilook image reconstruction

In order to modify the

ISAR data to imitate CW data, the range values are correlated to create range profiles then each range profile is collapsed by summing together the complex range values in order to obtain a single intensity result per angle.

An FFT is performed on each subaperture to obtain the Doppler profile of each and thereby obtain the cross-range profile.

Tomographic image reconstruction builds up an image by non-coherently summing many one dimensional projections taken over the 360 degree rotation angle, as shown in the figure 3.

The target image is produced from applying the tomographic technique by applying either range profiles or cross-range profiles over the 360° rotation angle.

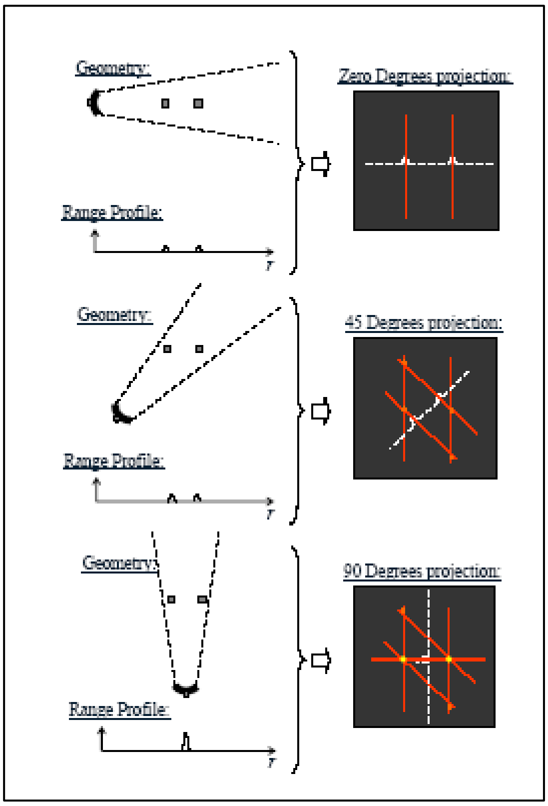

Figure 3: Tomographic image reconstruction

3.3. Spatial Resolution Limitations Results

According to the theory above is the minimum resolution for a 10GHz radar should be 1.5cm. However, the preliminary results shown here are for 30cm range resolution and 40cm cross-range resolution.

Figure 4 shows a pair of trihedrals imaged using the above techniques.

Figure 4(a) makes use of the multilook technique to combine the range profile data. Because the multilook technique superimposes range-Doppler images of 30 cm x 40 cm resolution, the overall circular resolution, over the 360 degrees of rotation angle, becomes a 30 cm circle. The point targets looks square thanks to the coarseness of the image. The effect will be the same when the resolution becomes 6.667 cm x 1.5 cm.

Figures 4(b) and 4(c) make use of the tomographic technique to form the image from range profiles and from cross-range profiles, respectively. The tomographic image using the range profiles should, ideally, look similar to the multilook image, although the scaling of each is not in proportion. The drawback of the tomographic technique is that by non-coherently summing the projections taken over the 360 degree rotation angle, artifacts are introduced.

In future work when the range resolution is 6.667 cm and the cross-range resolution is 1.5 cm, figure 4(b) will shrink to 6.667 cm squared resolution and figures 4(a) and 4(c) will shrink to 1.5 cm squared resolution.

If the resolutions improve to below $\lambda/2$ m, ambiguities will be introduced which may change the positioning of the point targets and may introduce multiple targets.

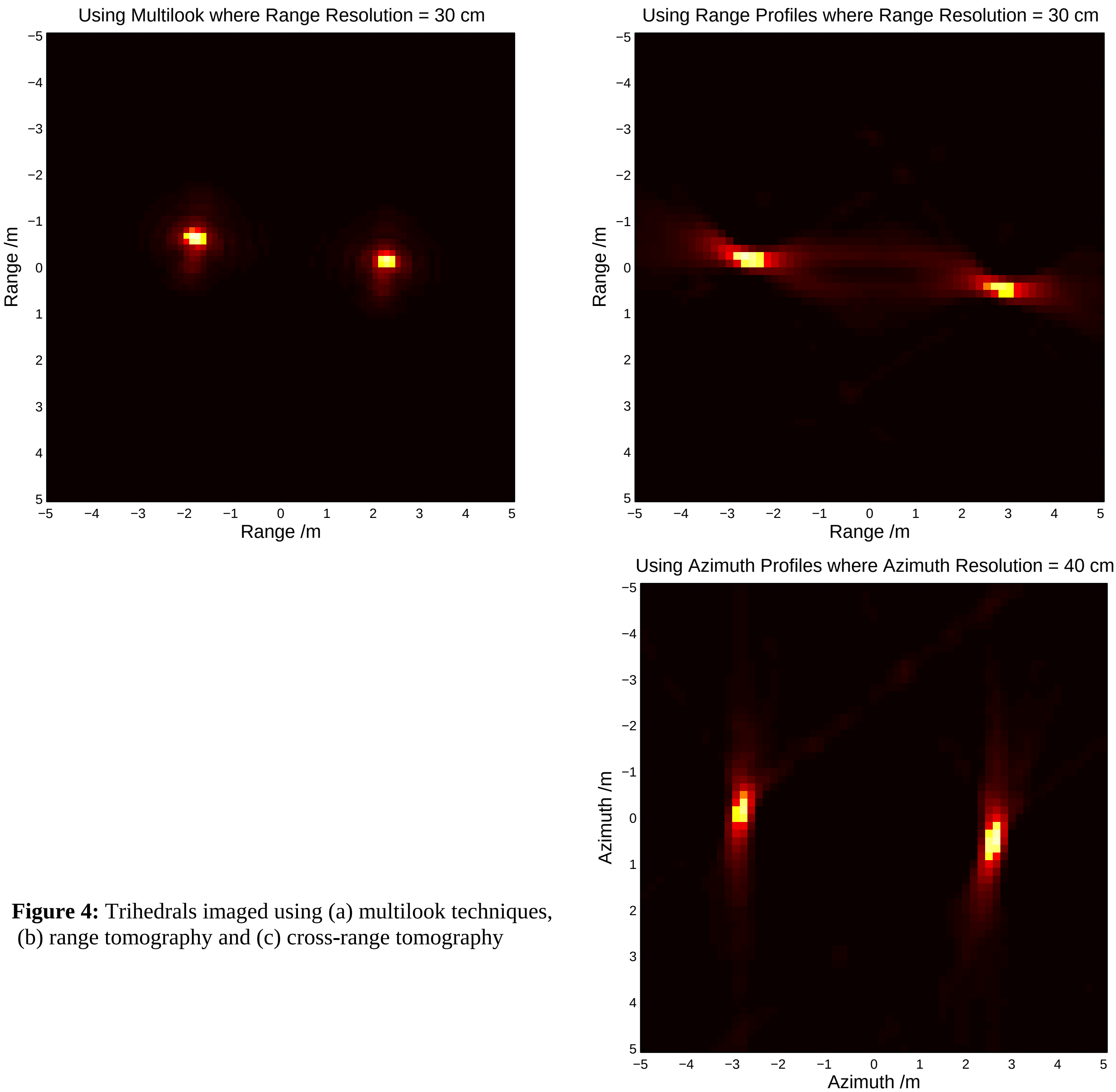

Figure 4: Trihedrals imaged using (a) multilook techniques, (b) range tomography and (c) cross-range tomography

4. FUTURE PLANS

Future work would involve trying various methods to overcome the TMT limitations.
They are to:
Prove the $\lambda/2$ spatial resolution limitations using tomographic images from experimental and simulated data.
Investigate the effect of these limitations on both the CW ambiguities and the tomographic ambiguities.
Investigate the effects of masking, multipath and speckle within these limitations

5. PhD THESIS WRITE UP

I am currently writing up my PhD thesis on this work and it will be made available to EOARD on completion.